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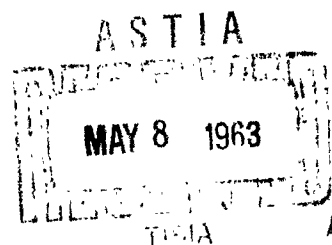
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REPORT NO. 563

SOME FACTORS INFLUENCING THE EFFECTIVE AUDITORY
INTENSIVE DIFFERENCE LIMEN

Michel Loeb, Ph. D.
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SOME FACTORS INFLUENCING THE EFFECTIVE AUDITORY
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ABSTRACT

SOME FACTORS INFLUENCING THE EFFECTIVE AUDITORY
INTENSIVE DIFFERENCE LIMEN

OBJECT

To determine probability of detection of changes in a steady noise stimulus and probability of detection of louder noise pulses in a train of pulses under unalerted conditions over appreciable periods of time at different levels of discrimination difficulty.

RESULTS

Changes in a steady stimulus were more readily detected than changes in pulses. At intermediate difficulty levels detections of changes in the steady stimulus declined with time; at intermediate and difficult levels detection of louder pulses declined with time. Progressive increases in latency were noted in some cases, and there was a general tendency for false detections to decline with time on task.

RECOMMENDATION

If an auditory display involving an intensive change is designed, it is preferable that such a display involve changes in a steady stimulus rather than changes in a series of stimuli.

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SOME FACTORS INFLUENCING THE EFFECTIVE AUDITORY INTENSIVE DIFFERENCE LIMEN¹

I. INTRODUCTION

It is generally agreed that the auditory intensive difference limen (DL) is a function of the particular psychophysical method employed. While a number of factors (e. g., necessity for forced choice, absolute intensity, psychophysical method, etc.) have been shown to influence the magnitude of the DL (1-5), the values for the auditory intensive DL at moderate or high stimulus intensity levels tend to be on the order of a fraction of a decibel.

In all of the studies known to the authors, the observers were alerted immediately prior to the presentation of a stimulus. However, in most practical situations, an observer must detect changes in intensity occurring randomly over long periods of time. Accurate estimates of unalerted thresholds are currently not available.

In addition to the effect of the alerting signal, two other factors seem worthy of attention. One of these is the duration of the period during which discriminations are to be made; the other, the kind of discrimination to be made.

It has been shown, particularly in experiments employing visual displays, that efficiency of detection of the presence of signal declines as a function of time on task (6, 7). On the other hand, detection of the presence of auditory stimuli does not seem to decline as a function of time on task (8, 9), though there is some evidence that latency of response to stimuli increases (10). Decrements in ability to discriminate changes in pitch (11), duration (6), and intensity (12, 13) of acoustic stimuli have, however, been reported. The data for detection of changes in intensity of acoustic signals have not been given in such a manner that effective DL or changes in the DL could be determined.

Various theories have been advanced to account for the temporal changes in performance. Mackworth (6) has suggested that a watch-keeping session is comparable to a conditioning situation and that a cumulative inhibition is generated that increases with successive detections. Deese (14) explains the performance decrements in terms

¹This research was aided by a contract between the Office of The Surgeon General, Department of the Army, and the University of Louisville.

of adjustment of subjective expectancies to the actual experimental schedule of signals. Holland (15) and Hickey and Blair (16), among others, have taken the position that: (1) subjects must perform "observing responses" in order to detect signals, (2) that the detection of a signal is somehow reinforcing, and (3) that since this reinforcement occurs only occasionally, the observing responses tend to extinguish with time on task. Another approach, mentioned by Deese (14), Broadbent (7), and others, stemming from a number of investigations (especially some by Hebb), considers that a varied background of stimulation is necessary to maintain normal activation or arousal and suggests that the performance is attributable to a progressive lowering of activation level in the monotonous monitoring situation. Broadbent has also advanced the hypothesis that an individual performing a monitoring task initially behaves as a filter biased to receive information from the signal display and that with time on task there is an increasing tendency to temporarily shift to receive other, irrelevant information. Sharpless and Jasper (17) have suggested that the performance decrement might be attributable to the progressive decrement in central neural responding (habituation) which they, and other experimenters (18), have reported. Egan, Greenberg, and Schulman (19) have noted that false detections tend to decline with time and failures of detection tend to increase. They therefore suggest that the progressive decline is attributable to a continuing shift in the detection criterion rather than a true decline in sensitivity.

Unfortunately, all of these theories (except, perhaps, the first) appear to have unique merit in explaining only certain of the experimental findings. Moreover, they are not mutually exclusive.

A factor other than time on task which might be expected to influence the DL is the nature of the discrimination, or type of detection task. Two classes of discrimination tasks may be defined, one involving detection of differences in intensity of temporally discrete stimuli (pulses) and the other the detection of an intensity difference in a stimulus continuously present. While the thresholds for the two types of tasks have been reported as different by some investigators (3-5), it is generally agreed that differences in DL are of the order of less than a decibel under alerted conditions using either procedure.

The theories of performance decrement enumerated above make no prediction as to the relative efficiency of detection of more intense pulse in a train of otherwise uniform pulses and an intensity change in an otherwise constant stimulus. However, the habituation hypothesis (and possibly other filtering hypotheses) would lead one to examine

these conditions and to predict differences in detection, if certain assumptions are made. Apparently the magnitude of the habituation effect is a direct function of number of unreinforced stimuli (17-19). When the observer is to detect a slightly more intense pulse in a train of otherwise uniform pulses, there is a large number of unreinforced stimuli, and considerable habituation should occur. If the more intense (signal) pulse closely resembles the uniform (non-signal) pulses in intensity and spectrum, such habituation should influence the probability of response and speed of responding to the signal. Similarly, when the signal to be detected is an amplitude change in a steady background of sound, it is less clear what degree of habituation should result. If the central nervous system reacts to the acoustic background between signals as a single, very long, non-signal stimulus, probably little habituation would occur.

However, if the nervous system somehow samples this background between signals so that, effectively, a number of irrelevant stimuli are received between signals, this would not be the case. If the sampling rate in the continuous amplitude change detection situation is less than the rate of stimulus presentation in the louder pulse detection case, habituation should be smaller in the continuous amplitude change situation than in the pulse detection situation but if the sampling rate exceeds the rate of pulse presentation, the converse should be true. Admittedly this is highly speculative; however, the point remains that differential habituation might be expected for detection of a louder pulse in a series of pulses as compared to detection of a brief change in amplitude of a steady stimulus.

A modification of the observing response hypothesis previously cited (15, 16) might also lead one to predict differential detection for different kinds of auditory stimuli. Assume that for efficient detection of an intensity change the monitor must have observed the comparison (non-signal) acoustic stimulus within a brief period before the change, perhaps because of a memory effect. Assume further that some kind of observing response (e. g., a certain type of breathing, refraining from swallowing, restriction of body movement, or the like) facilitates such observation and that these observing responses progressively extinguish or become less frequent with time on task. If the observing responses are made frequently, and the acoustic background between signals (amplitude changes) is continuous, there will be a high probability that the comparison or background stimulus will be observed within the period before the amplitude change. If the comparison stimulus between amplitude change is non-continuous (pulsed), however, it is more probable that the observing responses within the period just before the amplitude change will not coincide with the

time of presentation of the comparison (non-signal) stimulus, and efficiency of discrimination will thereby be lessened. In other words, if the assumptions are correct, efficiency of detection of an amplitude change in a continuous signal will be greater than the efficiency of detection of more intense pulse in a pulse train. With passing time, as observing responses become less frequent, differences in detection for the two kinds of auditory displays should increase.

The experiment to be described was designed to determine the influence of type and difficulty of discrimination on efficiency of detection of incremental signals over an extended period of time.

II. METHOD

Subjects. Eighteen observers, all students at the University of Louisville, were employed as subjects. Observers were paid \$2.00 per experimental session, and a \$20.00 prize was awarded the "best" subject. Eleven of the observers were men and seven were women. No attempt was made to assess the influence of observers' sex on performance. Observer age ranged from 19 to 34 years with a median of 19.5 years. No audiometric screening for hearing deficit was performed but several subjects with obvious hearing losses were rejected.

Design. The experimental design was, roughly, a 2×3 factorial design, the first factor being type of task and the second discrimination difficulty level. Every observer served under each of the six conditions, defined by the two types of signals and the three Discrimination Difficulty Levels. Types of signals were Steady Hiss (SH) and Pulse Train (PT), and Discrimination Difficulty Levels were easy, moderate, difficult, as defined below. Order of presentation of condition was counter-balanced over each of three sets of six observers in Latin square design. Six 100 minute sessions on different days were used with only one condition in effect per 100 minute session.

Procedure. Preliminary threshold measurements (method of limits; five ascending and five descending runs) were made to establish an absolute threshold for each subject. Zero dB sensation level (SL) was defined as the intensity detected 50 per cent of the time.

In the SH condition the observer was asked to detect an intensity increment imposed on a continuous 60 dB SL random noise, the increments for the difficult, moderate, and easy discrimination being, respectively, 0.6, 1.35, and 2.10 dB. In the PT conditions pulses having

an amplitude 60 dB (SL) and a duration of 0.5 seconds occurred every 2.5 seconds. Aperiodically, increments in intensity of, respectively, 2.1, 3.6, and 5.1 dB (difficult, moderate, and easy discriminations) were added to the pulses. Conditions are summarized in Table 1.

TABLE 1

Intensity Increments for Discrimination
Difficulty Levels for SH and PT Conditions

Discrimination Difficulty Level	Steady Hiss (dB)	Pulse Train (dB)
Easy	2.10	5.10
Moderate	1.35	3.60
Difficult	0.60	2.10

Under both sets of conditions increments in intensity occurred at intervals of 60, 90, 120, 150, or 180 seconds, determined randomly with the restriction that each increment occurred twice in each 20 minute period; increments had a duration of 0.5 seconds and a rise time of less than 1.0 ms.

Apparatus. The experiment was conducted in a sound-shielded room in which ambient sound level was approximately 35 dB (SPL). The random noise for the experimental stimuli was generated by a General Radio Random Noise Generator (Type 1390) and a pair of PDR-8 phones in Willson Sound Barrier Muffs, the latter producing an additional 15-45 dB (frequency dependent) attenuation of the ambient sound. Signal intensity was adjusted by General Radio attenuators (Type 1450-hp). Duration of signals was controlled by Hunter Timers and inter-signals interval by a Gerbrands Program Timer.

Supplementary Experiment. Analysis of results for the conditions described above indicate that the "difficult" condition for the PT task was not as difficult as might be desired. It was decided to extend the experiment by adding a more difficult condition, and a new group of 18 subjects was run under conditions PT 2.10, and PT 1.35, corresponding to increments of 2.10 dB and 1.35 dB. The PT 2.10

condition replicated the corresponding condition in the original experiment. Results of the Supplementary Experiment were analyzed separately.

III. RESULTS

During each 100 minute session 50 signals were presented for detection, 10 occurring in each 20 minute period. The observer's behavior was scored in terms of response time (Latency), errors of omission (Misses), and errors of commission (False Detections). If the observer responded within 3 seconds of onset of a signal his response was assigned the actual Latency of the response; if he did not respond within 3 seconds the response was scored a Miss.

Inspection of Figures 1, 2, and 3 showing mean number of Misses, means of median Latencies, and mean False Detections, leaves one with the impression of a high degree of relationship between the three measures of response--particularly between Misses and Latency measures. To the extent that the data are correlated, analyses of the different measures are not independent. A rather high degree of relationship is reflected in Table 2 containing product moment correlation coefficients. The coefficients contained in Table 2 are calculated over a

TABLE 2

Correlations of Means for Successive
20 Minute Periods (15 Pairs of Measures)

Latency vs. Misses		Latency vs. False Detections		Misses vs. False Detections	
SH	PT	SH	PT	SH	PT
.978	.924	.935	.448	.869	.425

set of 15 pairs of measures, no distinction being made with regard to intensity levels. The correlations are all large and positive and reflect the gross effects of the intensity increments. The correlation coefficients in Table 3 are for sets of 5 pairs of measures for a given intensity increment. Latencies and Misses are for the most part positively correlated, Latencies and False Detections negatively correlated, and Misses and False Detections negatively correlated. The

TABLE 3
Correlations of Means for 20 Minute Periods
With Intensity Level Condition

Latency vs. Misses		Latency vs. False Detections		Misses vs. False Detections	
SH	PT	SH	PT	SH	PT
(dB)					
(.60) .595	(2.10) .752	-.834	-.717	-.689	-.767
(1.35) .905	(3.60) .792	-.986	-.921	-.945	-.861
(2.10) .135	(5.10) -.590	-.042	.142	.560	-.586

magnitudes of the correlations are relatively small for the easy discrimination conditions. These correlations reflect, in all probability, temporal trends of the experimental measures, discussed below.

In the statistical analysis of the data corresponding to Figure 1, Figure 2, and Figure 3, an attempt has been made to answer two questions: (1) Are the apparent differences between curves significant? (2) Are there temporal trends in the data?

Two approaches have been made to the first question: (a) In most of the figures there is no overlap between curves and it can be shown that such an ordering, if assignment is random, has a probability on the order of 3×10^{-6} ; (b) Analyses of variance were computed in which sums of squares were divided into three parts corresponding to intensity levels, trials, and a remainder.

In attacking the second question, i. e., trends, two methods have been employed: (a) Comparison of end points of curves (first 20 minute period with last), using the Wilcoxon T, and (b) Analysis of variance using orthogonal polynomials, as described in Anderson and Bancroft (21). In justification of the application of this method, it may be observed that while the raw data give an appearance of non-normality, the means have a relatively normal distribution.

Misses. Figure 1 shows the means of Misses in successive 20 minute periods. In the SH condition it is apparent that there were relatively few Misses (0 to 10 per cent), at the 1.35 and 2.10 dB levels and a large number of Misses at the 0.6 level (of the order of 70 per cent). The differences between the curves are highly significant

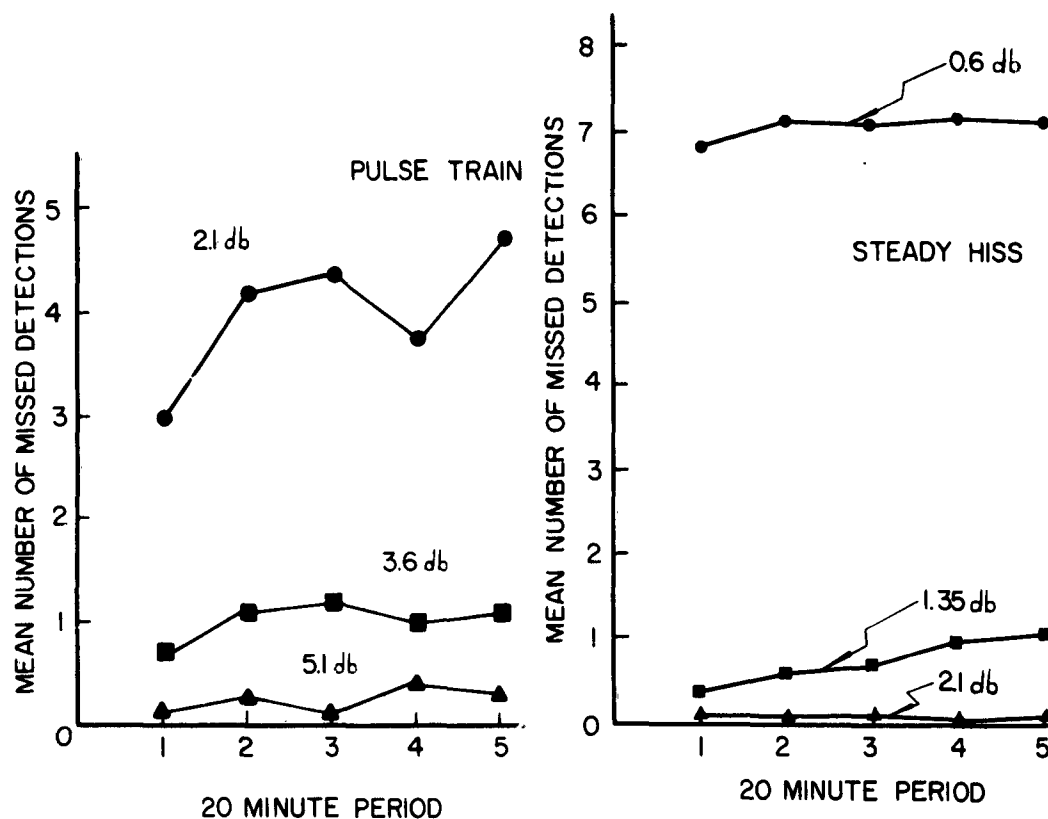


Fig. 1. Misses in the principal experiment.

($p \leq .01$) as inferred from both tests described above. In the PT conditions there were relatively few Misses at high intensities, 2 to 5 per cent for the 5.1 dB condition and 7 to 10 per cent for the 3.6 dB condition. A substantial number of Misses (40 per cent) was observed for the 2.1 dB pulse increment. Again, each of the curves differs from the others at a high level of significance. It is also noteworthy that the Misses in the SH 1.35 condition were significantly fewer than in the PT 2.10 condition ($p \leq 0.01$) or the PT 3.60 condition ($p \leq 0.05$) and not significantly different from those in the PT 5.10 condition.

To determine the significance of the apparent trends in the Misses, for example, the increasing numbers of Misses in PT 2.1, and SH 1.35, we have compared end points of curves using the Wilcoxon T test and have computed the linear components of sums of squares by the method of orthogonal polynomials, described above. The results of the two analyses are consistent with one another and summarized in Table 4. Misses increased significantly only for the SH 1.35 condition ($p \leq .02$) and the PT 2.10 condition ($p \leq .01$).

TABLE 4
Significance of Trends in Misses

		Wilcoxon	Orthogonal Polynomials
SH	0.60	ns	ns
	1.35	$p \leq .01$	$.01 < p < .02$
	2.10	ns	ns
PT	2.10	$p \leq .01$	$p \leq .01$
	3.60	ns	ns
	5.10	ns	ns

Latencies. Figure 2 exhibits the Latencies as a function of successive 20 minute periods. Each point is the mean of the medians for 18 subjects. Since substantial numbers of Misses were encountered, as recorded above, it was necessary to supply Latencies as the basis for the calculated means. Where there were no responses by an observer within a 20 minute period, the observer was assigned a Latency equal to the mean for the remaining periods.

It is to be noted that there is no overlap of the curves. An analysis of variance indicates the curves to be different at better than the .01 level and by the argument cited above the difference has a probability on the order of 3×10^{-6} . In both instances, i. e., for both

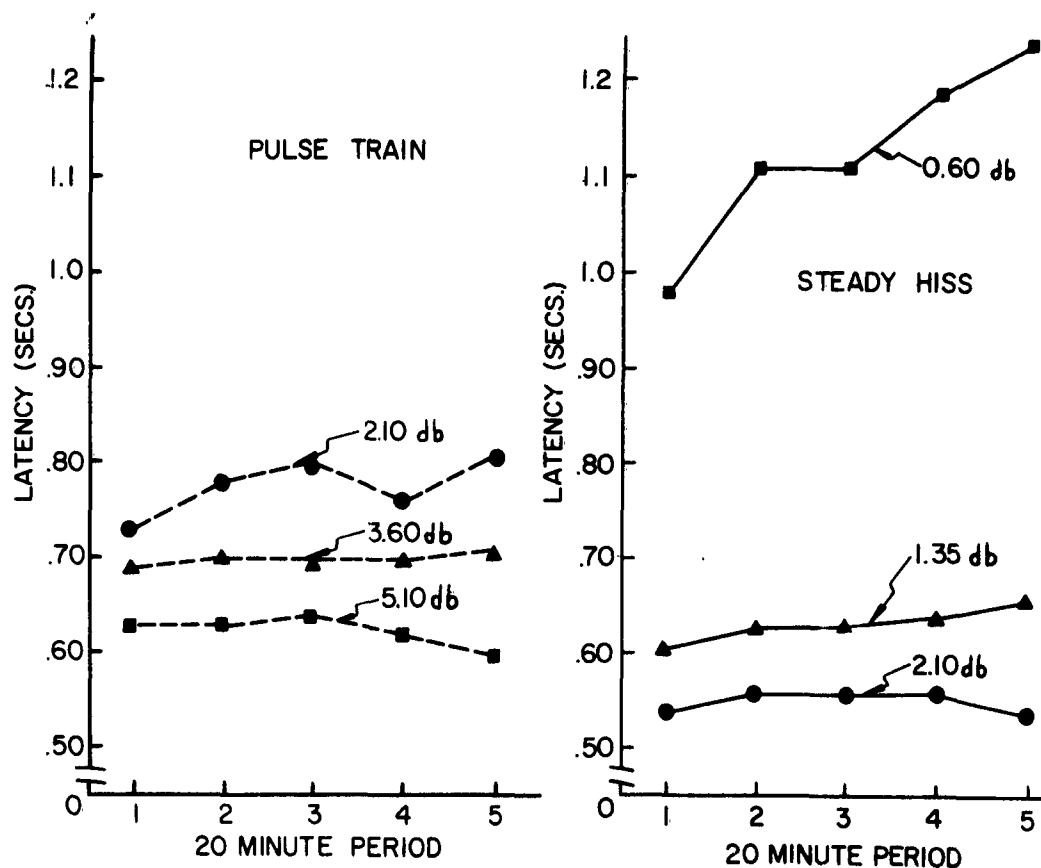


Fig. 2. Response Latency in the principal experiment.

types of signals, there is an apparent increase in Latency measures at the most difficult discrimination levels. Note also that mean Latency for detection of 0.6 dB increments in SH is consistently higher than that for any other condition. On the other hand, the mean Latencies for the 2.1 dB increments in SH are consistently lower than that for any other condition. If we accept the assumption that long reaction time is a correlate of high difficulty of discrimination (22), it follows that detection of 0.6 dB increment in SH is relatively difficult, detection of 2.1 dB increment in SH is relatively easy, and the other detection tasks are intermediate with regard to ease of discrimination. Differences in Latencies as a function of stimulus intensity within SH and PT conditions are highly significant ($p \leq 0.01$). The apparent increases in response Latencies between first and last blocks of trials are significant at levels indicated in the first column of Table 5. Significant

TABLE 5
Significance of Trends in Latency

		Wilcoxon	Orthogonal Polynomials
SH	0.6	$p \leq .05$	$p \leq .05$
	1.35	$p \leq .05$	$.05 \leq p < .10$
	2.10	ns	ns
PT	2.10	$p \leq .01$	$p \leq .02$
	3.40	ns	ns
	4.70	ns	ns

linear components of sums of squares for the mean Latencies for successive 20 minute periods are indicated in the second column of Table 5.

False Detections. Figure 3 exhibits the mean numbers of False Detections during successive 20 minute periods.

The primary characteristic of these curves is the relatively large number of False Detections during the first 20 minute period followed by a more or less gradual decline during the remaining periods. The initially large number of False Detections is particularly noticeable for all PT conditions and for the most difficult SH condition. Analysis of variance indicates a real difference in number of False Detections ($p \leq .01$) as a function of intensity increments for both SH and PT conditions. Comparison of the first 20 minute period with the last for each by the Wilcoxon T indicates a significant decrease for all conditions except SH 0.6. An analysis of trends by orthogonal polynomials indicates a linear component significant at the 5 per cent level for the 0.6 and 1.35 dB SH conditions, and 2.10 dB PT as shown in Table 6. (While the curves for False Detections give the appearance of non-linear trends, and while other sets of data obtained in this laboratory

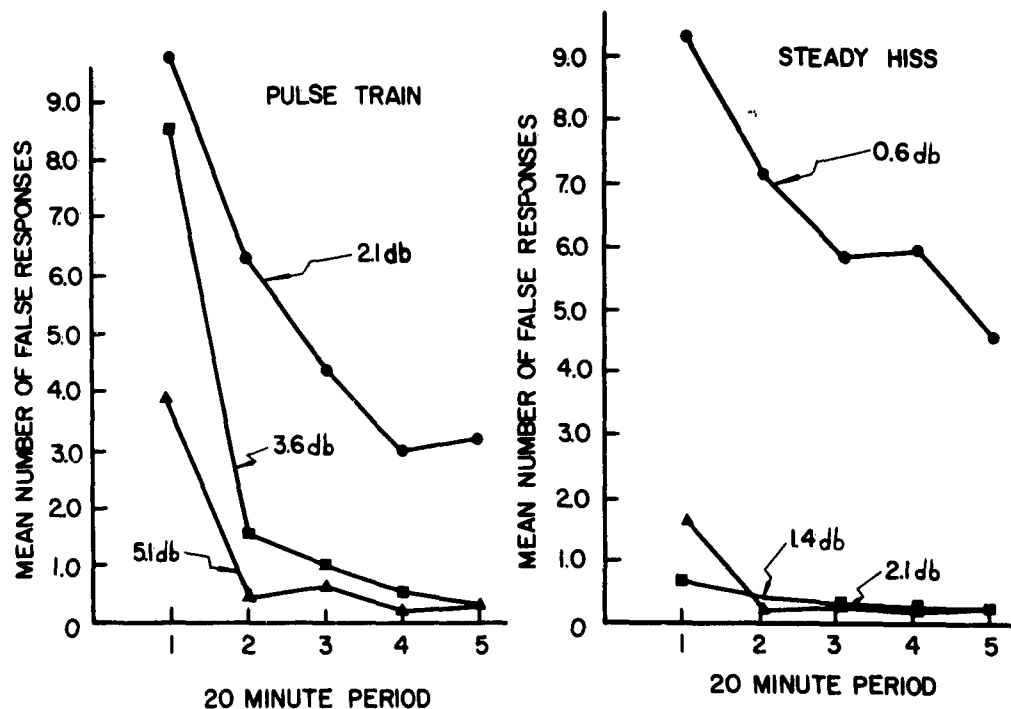


Fig. 3. False Detections in the principal experiment.

are similar, it is not reasonable to apply the orthogonal polynomials to assess the significance of quadratic and higher order effects with so few values of the independent variable.)

Supplementary Experiment. Misses, Latency, and False Detections for the Supplementary Experiment are shown in Figures 4, 5, and 6, respectively. Differences between conditions and between the first and last blocks of trials were tested for each experimental measure by the Wilcoxon T test, and linear trends were assessed by computing sums of squares due to linear by means of orthogonal polynomials.

Comparison of Misses in Figure 1 and Figure 4 indicates the comparability of the two experiments. In both cases there is a linear trend, and other numbers of Misses are of the same order of magnitude. The end points are different at the .01 level by the Wilcoxon T and the linear sum of squares is significant at the .025 level. As might be expected, significantly more 1.35 dB signals were missed than 2.10 dB signals ($p \leq .01$).

TABLE 6*

Significance of Trends in False Detections

		Wilcoxon	Orthogonal Polynomials
	.6	ns	$p \leq .05$
SH	1.35	$p \leq .05$	$p \leq .05$
	2.10	$p \leq .05$	ns
	2.10	$p \leq .01$	$p \leq .05$
PT	3.60	$p \leq .01$	ns
	5.10	$p \leq .01$	ns

*Inspection of the curves for False Detections leaves the impression of non-linearity and suggests the computation of higher order components of the variance. But the limited number of points argues against this application of orthogonal polynomials.

A similar finding for Latency was observed. A trend for an increase as a function of blocks of trials is apparent, as before, but not statistically significant. Variability of Latency was relatively large in the Supplementary Experiment.

False Detections appeared to be somewhat more numerous for the 2.10 dB PT condition of Supplementary Experiment than in the previous one. A progressive decrease in False Detections was noted ($p \leq .01$) by Wilcoxon T, and the responses were significantly more numerous for the condition with the less intense signal level--PT 1.35--($p \leq .01$). Some evidence of a quadratic component results from an orthogonal polynomial analysis of the False Detection data.

The reason for the considerable change in Latency and the small change in False Detections in the Supplementary Experiment cannot be established. The differences may reflect differences in subject population. It should be noted, however, that subjects in the first

experiment underwent six sessions while those in the subsequent experiment underwent only two.

It appears that in the Supplementary Experiment, the effective PT threshold was greater than 1.35 dB at the beginning of the session and smaller than 2.10 dB, but more closely approximated the former value. At the end of the session the effective threshold would appear to have been approximately 2.10 dB.

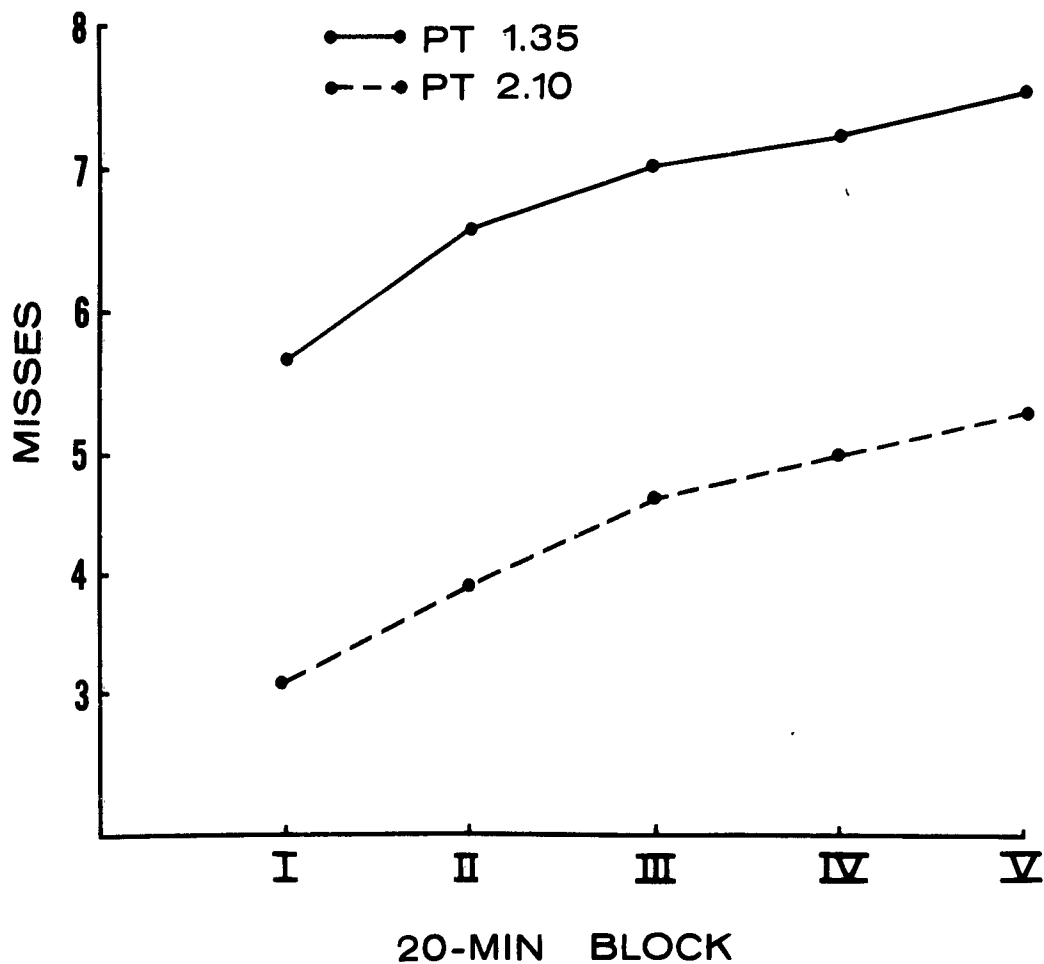


Fig. 4. Misses in the Supplementary Experiment.

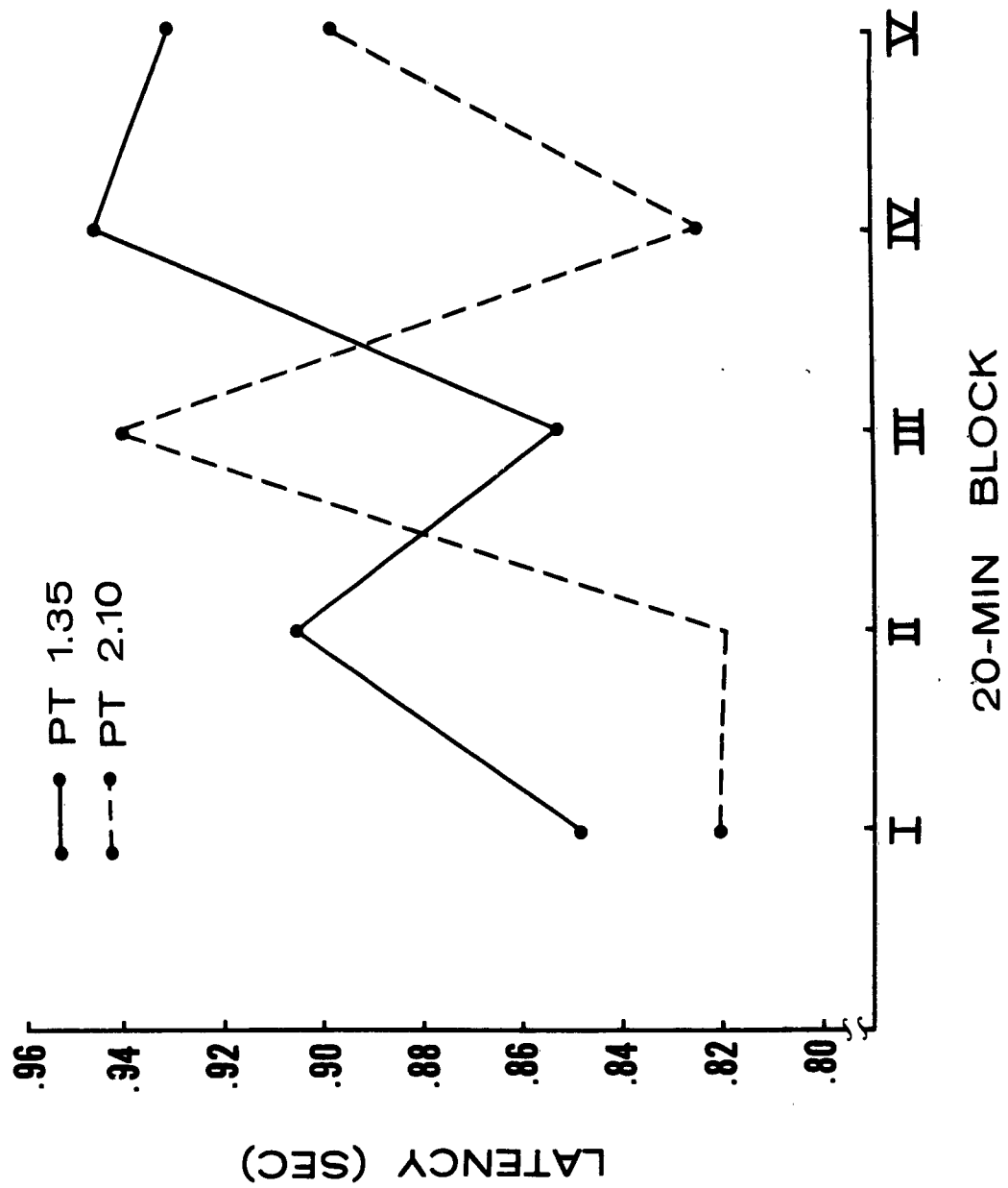


Fig. 5. Response Latency in the Supplementary Experiment.

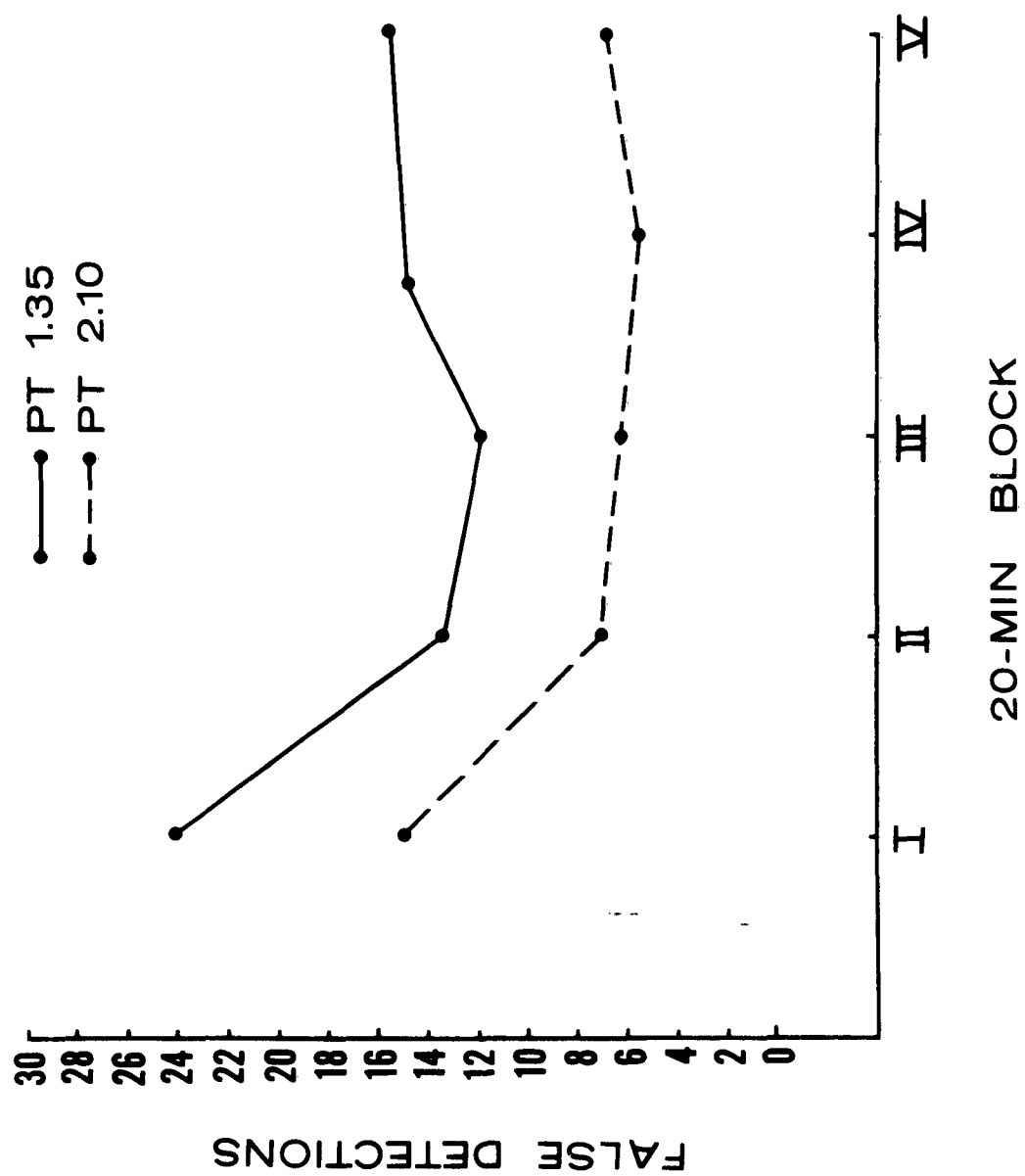


Fig. 6. False Detections in the Supplementary Experiment.

IV. DISCUSSION

When observers are asked to report changes in intensity of noise, it is apparent that such signals are detected much more efficiently when they consist of occasional increments in level of a continuous noise rather than occasional louder pulses within a train of periodic pulses. Moreover, there is a general tendency for quality of performance, as reflected in errors of omission and response time to deteriorate as a function of time on task, for the more difficult discriminations. It appears that both increases in False Detections, failures of detection and increases in Latency reflect increased difficulty of discrimination.

Another way to phrase the findings is to state that the effective auditory difference limen is appreciably smaller when observers are to detect alterations in intensity than when they are to detect pulses more intense than others in a pulse train. There is also some evidence that the effective DL increases with time on task, as signal detections on tasks of intermediate and appreciable difficulty (SH 1.35 PT 2.1, PT 1.35) declined. It is surprising that no significant change in detection occurred for the most difficult SH condition (SH 0.6).

If we accept the classical definition of threshold as the point at which 50 per cent of the signals are detected and ignore, for the time being, False Detections, then the threshold for the case where increments in continuous noise are to be detected (SH) is between 0.6 and 1.35 dB--approximately 0.9 dB. The decline in SH threshold with time is small. The effective DL for detection of discrete signals of greater intensity (the PT difference limen) is between 1.35 and 2.1 dB at the beginning of a watch session. At the conclusion of the 100-minute session, the effective DL for the PT conditions might best be estimated as approximately 2.1 dB.

In the practical situation one would rarely be interested in the effective 50 per cent detection point. (Still more rarely would one be interested in the levels for 50 per cent detection under alerted, forced choice conditions, though such values for the auditory intensive difference limen are the ones given in human engineering handbooks (24, 25).) A designer of equipment would probably prefer to know at what level a high percentage of signals--perhaps 90 per cent or 95 per cent or more--would be detected. Our results suggest that for SH, detection discrimination of 1.4 dB increments may be made more than 90 per cent of the time for 100 minute periods, though at the end of that time efficiency is not quite that high. SH increments of 2.1 dB may be detected more

than 95 per cent of the time over such a period and there is no apparent decline in performance.

If it is desired that louder pulses in an otherwise uniform pulse train be detected 90 per cent of the time, the pulses should exceed intensity of others in the train by approximately 3.6 dB. For 95 per cent detection, the increment should be approximately 5.1 dB.

It is obvious that these values would be somewhat different if other signal schedules, motivational conditions, subject-populations, signals, spectra, or levels of experience had been involved. However, they are more generally useful values than those obtained experimentally under alerted conditions.

It is not immediately apparent how simple expectancy or reinforcement hypotheses, as stated above, account for the considerable differences in detection for SH and PT signals or the apparently greater tendencies toward a decline in detections for the PT condition. As was indicated earlier, a habituation hypothesis or some other kind of filtering concept or a modified observing response theory could be employed to account for such findings. It is also possible that a different sort of reinforcement theory, in which reinforcement is formulated in terms of ratio of signals to irrelevant stimuli, might also account for the differences observed (Cf. Colquhoun) (25).

The significance of the progressive decline in False Detections is not known, though others have reported similar results (12, 13). It may be due to a progressive decline in responding, but the decline for False Detections is much more marked than the decline in detections. Possibly it represents a learning effect. Initially observers tend to overestimate the frequency at which signals will be presented and, especially at low increments, when no signals are forthcoming, they probably tend to hallucinate or to respond to physiological noise. The data suggest that False Detections are more common in first sessions than later, but the number of subjects and replications was too small to test this hypothesis.

The Egan, Greenberg, and Schulman hypothesis (criterion change) (19), considers both the progressive change in False Detections and Misses, and the results of the present experiment are not in conflict with such an explanation. The differences in performance for the two kinds of discriminations may also in part reflect such a factor, but it seems dubious that the differences in level and in trend obtained are entirely explicable in these terms. It is noteworthy, that performance

on some visual vigilance tasks (e.g., the Mackworth clock task (6)) is characterized by a considerable number of missed signals, considerable increase in missed signals with time, and a very small number of False Detections, not increasing systematically with time.

A definitive test of the interpretations by Egan *et al* might be performed--as they suggest--by employing procedures involving multiple confidence ratings (20) or responding at different times under different criteria (26). Such experiments should be performed, but it seems dubious that the changes observed in all vigilance tasks may be explained on this basis.

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